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## CERTIFICATE

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that annexed is a true copy of the Provisional Specification as filed on 15 November 2002 with an application for Letters Patent number 522635 made by AGRESEARCH LIMITED.

I further certify that the Provisional Specification has since been post-dated to 17 December 2002 under Section 12(3) of the Patents Act 1953.

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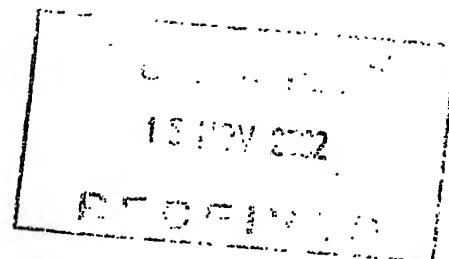
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330 High Street, Lower Hutt and 17 Toop Street, Scavview  
PO Box 30687, Lower Hutt, New Zealand or DX SX 11129, Wellington  
Phone: +64 4 560 1600, Fax: +64 4 560 1691, [www.iponz.govt.nz](http://www.iponz.govt.nz)

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**PATENTS ACT 1953**  
**PROVISIONAL SPECIFICATION**

**MICROWAVE TEMPERATURE MEASUREMENT APPARATUS AND  
METHOD**

I/WE      AgResearch Limited, a New Zealand company duly incorporated pursuant to the Crown Research Institutes Act 1992 and having its Registered Office at 5<sup>th</sup> Floor, Tower Block, Ruakura Research Centre, East Street, Hamilton, New Zealand

## MICROWAVE TEMPERATURE MEASUREMENT APPARATUS AND METHOD

### TECHNICAL FIELD

The present invention relates to a means of temperature measurement using microwaves, and more particularly to temperature measurement of frozen/chilled 5 organic matter such as frozen meat.

### BACKGROUND ART

The practice of chilling and freezing produce for both transport and storage has gained widespread acceptance and is the primary method of ensuring food preservation in the journey from the food processing plant to customer. Bacterial growth poses a serious 10 health risk for food which is not maintained at a safe temperature during the different stages in the supply chain, typically including the end of production line packaging, storage on the manufacturers' premises, transit, and arrival at the retailer.

As a visual inspection of frozen food is incapable of determining the core temperature, the current standard procedure to determine whether a product is correctly frozen 15 requires insertion of a thermometer/thermal sensor through a hole drilled into the produce, and typically also through the product container. It will be appreciated that such a procedure is time consuming, difficult to automate and detrimental to the product tested. Furthermore, as frozen food products are often transported between several locations and storage sites such as in the export of frozen meat from a remote 20 country such as New Zealand, the temperature testing procedure would need to be repeated on numerous occasions.

It is thus unsurprising that such invasive temperature testing procedures are sometimes omitted in practice with a resultant danger that foodstuffs may be either insufficiently frozen with the corresponding health risk time or that energy is wasted due to 25 excessive freezing.

In order to address these difficulties, significant research has been devoted to non-invasive methods of temperature sensing. Microwave radiation interacts with organic matter in a manner which is particularly effective in relation to temperature measurement of frozen or chilled food.

- 5 Microwaves are energetic electromagnetic radiation (conventionally defined as having a frequency of between 1-300 GHz) which is capable of penetrating matter to a degree dependant on the radiation energy and the matter composition. Microwave radiation is used as a heating medium due to its capacity for stimulation or vibration of water molecules in organic matter thus causing localised temperature increases.
- 10 At typical ambient temperatures of foodstuffs such as meat being cooked in a domestic microwave ovens, the microwave radiation is only able to penetrate a few centimetres. As large cuts of meat or similar would often be thicker than a few centimetres, most microwave ovens rotate the radiated food to present the greatest penetrateable volume to microwave exposure. Stand-times are often also incorporated as part of the cooking process of voluminous foodstuffs to allow for heat conduction to provide additional cooking effect in regions unaffected by the microwaves.
- 15

However, the interaction of microwaves with organic matter is also temperature dependant. Microwave radiation is attenuated by passage through a given material according to a function which includes dependencies on both the temperature of the material and the frequency of the incident microwave radiation.

Significantly, the attenuation of the microwave radiation by the sample material drops sharply for temperatures below the freezing point, i.e., - the material effectively becomes transparent to microwave radiation. This characteristic change in attenuation is a well known feature of the interaction of microwaves and frozen produce.

- 20
- 25 Whilst this sharp change in transmittance (i.e. the inverse of attenuation) above and below the borderline of freezing temperatures may be used to indicate when a product

is definitely frozen, determining the exact temperature of a lightly frozen or chilled item requires an accurate measurement system with an elimination of unknown variables and other error sources. It is known to use a sensor or detector to measure the un-attenuated microwave radiation passing through the sample as a fraction of the 5 total microwave radiation transmitted by the microwave transmitter. This result may be used as a basis for calculating the temperature, or 'ice-fraction' of the sample.

However, the accuracy of such a system may be undermined by a number of factors. The microwave detector will be unable to discriminate between a microwave ray detected after transmission through the sample body and a ray which has been reflected 10 from some other object, or even received directly from the transmitter without having been transmitted through or reflected from anything, including the sample. Without eliminating or otherwise accounting for such potential error sources such as alternate beam paths, the detector will receive a false reading, resulting in incorrectly calculated sample temperature.

15 Various solutions to this difficulty has been attempted.

Miyakawa, M. (1993) *Tomographic measurement of temperature change in phantoms of the human body by chirp radar-type microwave computed tomography*, [Med. & Biol. Eng. & Comput., 31, S31-S36.] developed a microwave-based computed tomography system to measure temperature in the human body. A pair of small (9.53

20 by 19.1 mm) antennae are rotated around a (phantom of a) body immersed in saline solution to measure the attenuation of the microwave signal at each step of the rotation. The individual measurements are then mathematically combined using a computer to generate an image of the microwave attenuation formed from two-dimensional slices through the body.

25 To eliminate the problem of alternate beam paths (i.e. paths not passing through the body) interfering with the measurement, *Mikakawa* (1993) uses a bath of saline. As

saline has similar microwave attenuation to body fluid, immersing the body in saline minimised reflection and refraction as the beam entered the body. The body is then imaged at two different temperatures and the attenuations in the two images subtracted to show that they were different at different temperatures.

5 This technique has the drawbacks of;

- the physical and practical inconvenience of using a saline bath to minimize reflection and refraction;
- the requirement for a reference image to permit the subtraction of images to give a temperature measurement, and

10 • a measurement time of at least several seconds.

US Patent 5,341,814 *Van De Velde et al* (1994) teaches of a method for measuring the temperature of an object by detecting the thermal noise emitted by the object in the microwave frequency range. However, *Van De Velde* does acknowledge the following difficulty;

15 *In this connection, there are known microwave radiometry devices in which the microwave radiation emitted via an antenna is picked up and the signals received are routed to signal processing means which enable the temperature of the object in question to be determined.*

20 *However, one of the main problems encountered in microwave frequency radiometry resides in the matching of the antenna in respect of the material the temperature of which one wishes to know. Indeed, the antenna used has a reflection coefficient  $R_o$  and, as a result, the antenna is never perfectly matched, given that the objects to be measured generally have different configurations, sizes and properties.*

US Patent 4,346,716 *Carr* (1980) relates to the detection of tumors by measuring the differential rate at which tumors are heated by microwave energy compared with normal tissue, due to the fact that tumors are not cooled as effectively as normal tissue by flowing blood. The temperature measurement mechanism is based on passive 5 measurements of microwave emissions at 4.7 GHz, (as per *Van De Velde et al*), rather than the transmittance measurement.

US Patent 4,870,234 *Steers et al* (1989) relies on the same fundamental mechanism discussed earlier to distinguish frozen from unfrozen product, i.e. a measurement of the different microwave transmittance through material dependant on whether it is 10 frozen or unfrozen.

The *Steers et al* approach uses the rate of change in temperature of a reference material to measure the amount of microwave energy passing through the product rather than a microwave receiver. This method has the advantage of low cost and may provide an appropriate alternative in some applications. However, for applications requiring 15 temperature measurement of products in systems with a high throughput rate (such as in a meat processing plant), the method of *Steers et al* suffers from three serious disadvantages:

1. a single temperature measurement requires sufficient time for the reference material to heat measurably – requiring seconds or even tens of seconds and thus 20 limiting throughput;
2. the use of a microwave transmitter with sufficient power to measurably heat the reference material necessitates appropriate shielding structures which are generally inconvenient or impractical to implement in automated food processing plants, and

3. there is no provision disclosed for cooling the reference sample to facilitate rapid repeat temperature measurements.

Irrespective of a possible resolution of the first two disadvantages listed above, the third disadvantage would still prevent practical temperature measurements in a multi-sample temperature measurement scenario. Due to the absence of any cooling, the reference sample would eventually be heated to an equilibrium temperature from repeated measurements, thus preventing further reference sample temperature change implicit for any sample temperature measurements.

The 'Celsius' unit by Loma Systems™ is a microwave temperature measurement device, resembling a domestic microwave oven. After a sample is manually placed inside the fully enclosed cabinet (via a front door), the sample is irradiated by microwave radiation and a temperature measurement is taken, though the specific measurement mechanism used is not disclosed by Loma Systems™ in their promotional literature.

However, from the configuration of the device, it seems likely a similar system to that of *Van De Velde et al* is utilised, i.e. the temperature is calculated from the microwave radiation emitted or reflected from the irradiated object.

If such a mechanism is employed, the detector also receives microwaves which have been deflected, reflected and refracted from the enclosure interior. The temperature measurement thus needs to take account of all the radiation detected and not just those microwaves emanating from the sample.

Whilst this system may be suitable for measuring samples small enough to fit in the enclosure, this system does not lend itself to multi-sample measurements in high throughput applications.

A housing completely enclosing each sample is an unavoidable requirement as the microwave measurements would otherwise be affected by stray environmental electromagnetic radiation. Such a requirement would necessitate complex and costly mechanical systems to repeatedly manipulate samples from a production line into a 5 measurement housing, seal the enclosure, rapidly perform the temperature measurement, extract the sample and return to the production line.

It can be seen therefore that none of the above prior art provides a practical, non-invasive means suitable for incorporation in rapid sample throughput systems for determining the temperature of chilled or frozen produce or other water-rich 10 substances.

All references, including any patents or patent applications cited in this specification are hereby incorporated by reference. No admission is made that any reference constitutes prior art. The discussion of the references states what their authors assert, and the applicants reserve the right to challenge the accuracy and pertinency of the 15 cited documents.

It will be clearly understood that, although a number of prior art publications are referred to herein, this reference does not constitute an admission that any of these documents form part of the common general knowledge in the art, in New Zealand or in any other country.

20 It is acknowledged that the term 'comprise' may, under varying jurisdictions, be attributed with either an exclusive or an inclusive meaning. For the purpose of this specification, and unless otherwise noted, the term 'comprise' shall have an inclusive meaning - i.e. that it will be taken to mean an inclusion of not only the listed components it directly references, but also other non-specified components or 25 elements. This rationale will also be used when the term 'comprised' or 'comprising' is used in relation to one or more steps in a method or process.

It is an object of the present invention to address the foregoing problems or at least to provide the public with a useful choice.

Further aspects and advantages of the present invention will become apparent from the ensuing description which is given by way of example only.

## 5 DISCLOSURE OF INVENTION

According to one aspect of the present invention there is provided an apparatus for measuring the temperature of an object, said apparatus including:

- a microwave emitter and a microwave detector

characterised in that to perform temperature measurements, said microwave emitter is 10 positioned immediately adjacent the surface of said object and said detector is positioned on an opposing side of the object such that microwave detector solely receives any microwave radiation transmitted through the object from the microwave emitter.

According to another aspect of the present invention there is provided a method of 15 measuring the temperature of an object using microwave radiation, characterised by the steps of :

- positioning a microwave emitter immediately adjacent or in contact with a surface of said object;
- positioning a microwave detector on an opposing side of the object to said 20 emitter;

such that microwave detector solely receives any microwave radiation transmitted through the object from the microwave emitter.

As used herein, the term object is to be interpreted widely and includes any substance,

material, or organic matter, particularly those containing moisture and/or any other substance where the transmittivity of microwave energy changes measurably with temperature.

Preferably, said object is frozen, near frozen or chilled.

5 It will be appreciated however, the present invention is not necessarily be limited to the temperature measurements of frozen or chilled objects. Alternative (non-temperature related) uses may be made of the measurements produced by the present invention.

Preferably, the present invention further includes drive apparatus capable of reversibly placing the said microwave transmitter immediately adjacent to or in contact with a  
10 surface of the object.

Optionally, the present invention also includes drive apparatus capable of reversibly placing the said microwave receiver on an opposing side of said object to said transmitter.

According to one aspect of the present invention, said drive apparatus is a linear  
15 actuator operating substantially orthogonally to said primary axis of travel. Preferably, said drive apparatus includes, but is not limited to a pneumatic, hydraulic, electro-mechanical operated actuators.

Preferably, said detector is positioned in contact with said object. However, in an  
20 alternative embodiment, said detector is located proximate to, but not in contact with said object.

The present invention as described above confers a number of advantages over the prior art. There is no restriction on the test object size due to the need to place the object in an enclosure. Furthermore, the possible detection of erroneous microwaves

which have not been transmitted through the object is practically eliminated by placing the transmitter adjacent the object surface. Placing the detector immediately adjacent or in contact with the object also aides in ensuring only microwaves transmitted through the object are detected. Surprisingly, it has been found that locating the 5 detector at short distance from the object does not necessarily corrupt accurate temperature measurements.

The present invention is also ideally suited to rapid repeat temperature measurements of objects on a production line or the like. As there is no requirement for placing the object in a housing or enclosure, the dwell-time between measurements is not 10 exacerbated by removing the objects from a conveyor system or the like, placing in an enclosure of measurement, and (possibly) replacing on the conveyor system. Instead, the temperature of chilled or frozen objects may be measured directly on a conveyor or similar, thus speeding throughput significantly.

Thus, according to a further embodiment, said object is placed on a moving 15 conveyance located between the microwave emitter and detector.

A moving conveyance includes, but is not limited to conveyor systems, pallet handling systems, automated cargo transport system, robotic, manual or other human operated object handling and transportation system and the like.

Preferably, said conveyance has a primary axis of travel.

20 Thus, temperature measurements of successive may be provided by the combined operation of said conveyance system moving successive objects along said primary axis of travel between the microwave transmitter and detector and a said linear actuator moving the microwave transmitter (and optionally) the detector into and out of contact with an object when interposed between said microwave transmitter and detector.

25 It is thus also possible to scan a large object by making repeated temperature

measurements at different points or even continuous measurements as the emitter/detector is moved over the surface of the object.

However, it will be appreciated that the present invention need not necessarily be used in automated or multi object measurement application. The advantages of both 5 simplified equipment over other electronic non-invasive systems together with the improved accuracy, convenience and non-invasive characteristics compared to drilled core samples favour the present invention for any scale of operation/application.

It is entirely feasible for an operator to manually place the microwave emitter and detector on opposing sides of an object for a singular temperatures measurement.

#### 10 BRIEF DESCRIPTION OF DRAWINGS

Further aspects of the present invention will become apparent from the following description which is given by way of example only and with reference to the accompanying drawings in which:

15 Figure 1 shows a first side elevation of a preferred embodiment of the present invention;

Figure 2 shows a second side elevation of the embodiment shown in figure 1;

Figure 3 shows an enlarged view of the embodiment shown in figure1, and

Figure 4 shows an enlarged view of the embodiment shown in figure2.

#### BEST MODES FOR CARRYING OUT THE INVENTION

20 Figures 1-4 show a first embodiment of the present invention for temperature measurement of frozen meat boxes in a meat processing plant.

Figures 1 and 2 show an embodiment of the present invention in the form of a microwave temperature measurement apparatus (1), comprised of a microwave emitter

(2), a microwave detector (3), support frame (4) and a moving conveyance system in the form of conveyor system (5). This embodiment is primarily configured for measuring the temperature of frozen meat placed in standard meat cartons (6). Figures 3 and 4 show enlarged representations of the microwave emitter and detector (2, 3), 5 conveyor assembly (5) and carton (6).

The microwave emitter (2) is located at the lower end of drive apparatus in the form of a vertically orientated linear actuator (7) whilst the microwave detector (3) is fixed below the conveyor system (5) in a confronting relationship directly below the microwave emitter/actuator assembly (2, 7).

10 The microwave detector (3) and the exterior housing of actuator (7) are secured to the support frame (4). The conveyor system (5) is formed from a plurality of cylindrical rollers (8) located transversely across the width of the conveyor (5). Meat cartons (6) are driven along the conveyor (5) either actively or under the influence of gravity by inclining the conveyor (5).

15 The primary axis of travel of the cartons (6) along conveyor (5) passes between the microwave emitter and detector (2, 3) at which point a stop cylinder (9) raises from below the plane of the conveyor (5) surface to restrain the carton (6) while a temperature measurement is taken. A nudge bar (10) positions each carton laterally to align with the emitter/detector (2, 3) to account for any variation in alignment as 20 cartons are transported on the conveyor (5).

When the carton (6) is correctly positioned by the stop cylinder (9) and nudge bar (10) between the microwave emitter and detector (2, 3) respectively, the linear actuator (7) lowers the emitter (2) until contacting the surface of the carton (6). The microwave emitter (2) is then activated and a pulse of microwaves (not shown) are transmitted 25 through the carton (6) towards the detector (3). The degree of attenuation of the transmitted microwave beam provides an indication of the temperature of the carton

(6) and its contents, i.e. the frozen meat.

As the emitter is placed directly on the surface of the carton, all the microwaves emitted have to travel through the carton (6) before being either absorbed, or detected by the detector (3). This configuration reduces the possibility for any external  
5 reflection, refraction or other indirect routes from the emitter (2) to the detector (3).

Although the above embodiment shows the use of temperature measurements with a standard sized meat container, it will be appreciated that a variety of other objects/containers may be employed by configuring and dimensioning the present invention (1) accordingly. It will be further appreciated that alternative conveyance  
10 means to the conveyor system (5) may be employed.

In the embodiment shown, the microwave detector (3) is positioned a short distance below the carton (6) to allow for the passage of the conveyor system (5). It will be appreciated that in other embodiments, the detector (3) may be placed in contact with or immediately adjacent to the surface of the carton (6) to ensure no extraneous  
15 reflected or refracted microwaves are received by the detector (3). It has been found in practice however that separating the detector (3) from the surface of the object being the temperatures being measured (6) does not cause any appreciable degradation in the temperature measurement.

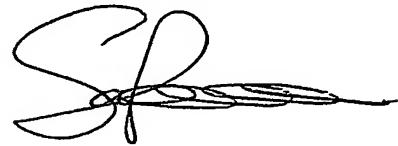
Thus, by virtue of the aforementioned configuration, the present invention provides an  
20 apparatus and a method for measuring the temperature of chilled and/or frozen objects without need to place the said objects in a measurement enclosure, and without obstructing the throughput of objects in continuous production/packaging or storage applications.

Aspects of the present invention have been described by way of example only and it  
25 should be appreciated that modifications and additions may be made thereto without

departing from the scope thereof.

AGRESEARCH LIMITED

By its Attorneys



JAMES & WELLS

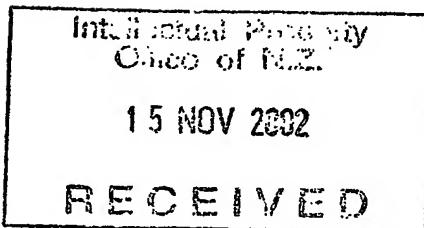


Figure 1

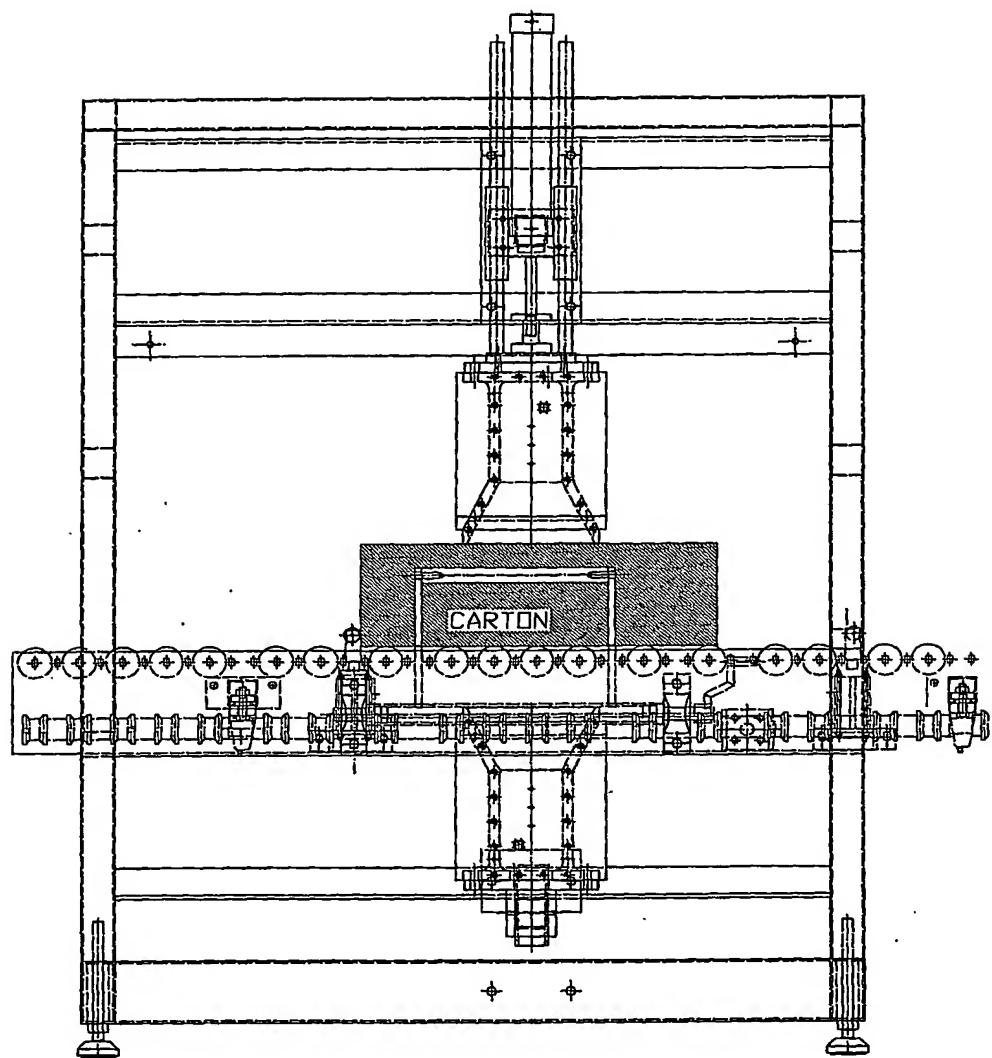
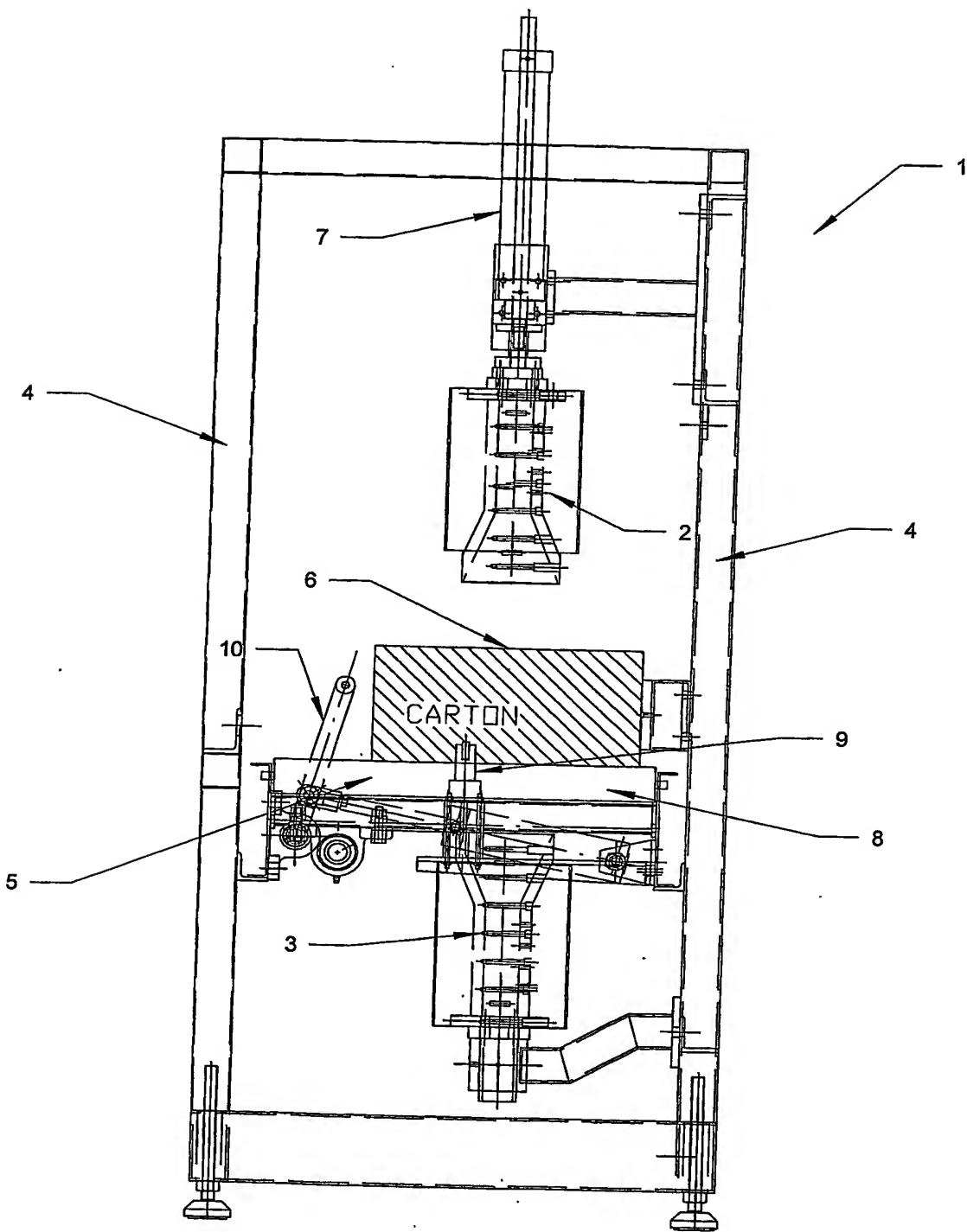
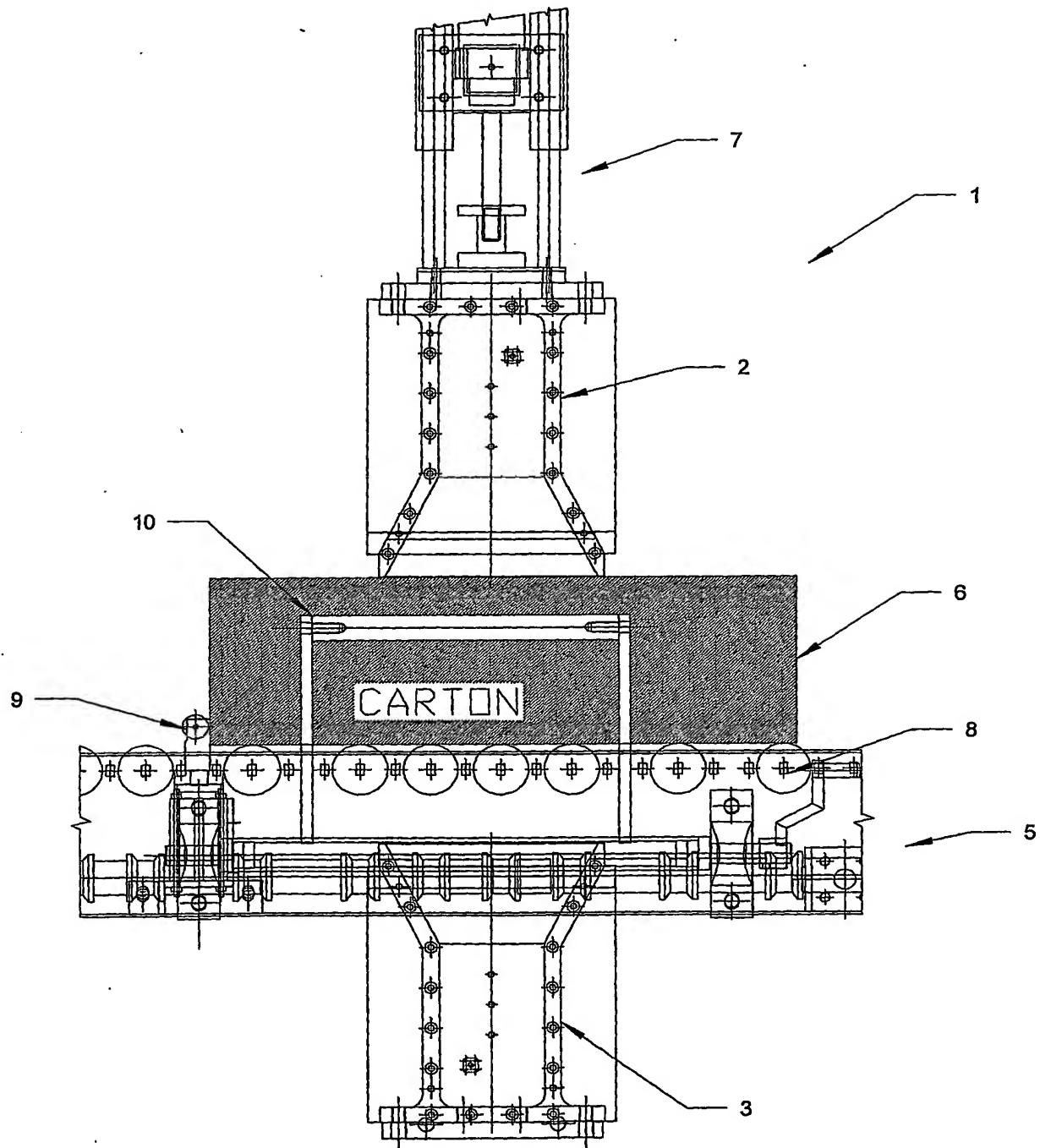


Figure 2



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Figure 3



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Figure 4